Crash and Ballistic Protective Flight Helmet

ABRAHAM L. LASTNIK

The U. S. Army Natick Laboratories has developed a helmet to upgrade head protection for Army aviators. This helmet exhibits greater impact energy-dissipating characteristics than other military helmets and also provides resistance to penetration by ballistic fragments.

While the Army's new helmet has the same configuration as the Navy's APH-6 and Air Force HGU-2A/P helmets, increased protection is achieved by making its shell of laminated nylon fabric instead of laminated glass cloth. Impact energy attenuation is further increased by lining the shell with ½-inch thick, four-pound density, expanded polystyrene plastic.

Subjected to two successive impacts of 160 foot-pounds in the same area, there was no evidence of bottoming, nor were accelerative forces in excess of 300 G's measured on an instrumented headform. Duration of impacts was not less than 6.0 milliseconds. The glass cloth helmet impacted with only 100 foot-pounds imparted 300 and 600 G's, with duration of impacts not exceeding 4.0 milliseconds.

STUDIES CONDUCTED by the United States Board for Aviation Accident Research[1] show that 97 per cent of all Army aircraft accidents are theoretically survivable.* It is in this category of accident that a protective helmet can play the most significant role. Army aviation accident reports during the 42-month period from July 1957 through December 1960 indicate that helmets prevent and reduce the severity of head injuries. The accidents studied involved 1,259 persons, of which 991 did not wear helmets and 268 did. Fatal head injuries were sustained by 5.9 and 1.1 per cent of each group, respectively.[3,1]

The standard helmet for Army aircraft crewmen is similar to helmets worn by the pilots of the Navy and Air Force, which are designated as APH-6 and HGU-2A/P, respectively.[5,4] Their crash protection is provided by a hard, rigid shell made from glass cloth laminated with polyester or epoxy resin and lined with ½-inch thick, crushable, expanded polystyrene plastic. To add to the head protection of the aircraft crewman and have him accept the new helmet with a minimum of testing and subjective controversy, the Army retained the configuration of the standard helmet and increased the crash protection by using improved energy-dissipating materials.

The New Helmet—The appearance of the new Army flight helmet developed by the U. S. Army Natick Laboratories (Figure 1) is similar to that of the standard helmet. Both contain impact energy-absorbing liners made of expanded polystyrene plastic, integral communications equipment, visor housing and an acrylic visor. Since the shell of the new helmet is made of laminated nylon fabric, it will be referred to as the "nylon helmet" whereas the standard helmet will be referred to as the "glass helmet." The weight of both is about the same, but the nylon shell was found to be considerably more durable.

Early impact studies with the Army's combat vehicle crewman's helmet (tanker's helmet) indicated its excellent impact energy-dissipating properties as compared with those of the standard flight helmet. Its shell structure also provides greater resistance to penetration by ballistic fragments. Although the tanker's helmet absorbs great quantities of energy, high-speed motion pictures reveal excessive transient deformation* in the impact area. This localized deflection of the helmet shell could cause head injury.

The shell of the combat vehicle crewman's helmet is made of multilayers of nylon cloth laminated with from 15 to 18 per cent phenol formaldehyde and polyvinyl butyral modified phenolic resins.[6] An investigation of this laminate with varied resin concentrations provided the following information about its energy-absorption properties.[7]

1. Resin concentration has no significant influence on a laminate's ability to resist penetration of ballistic

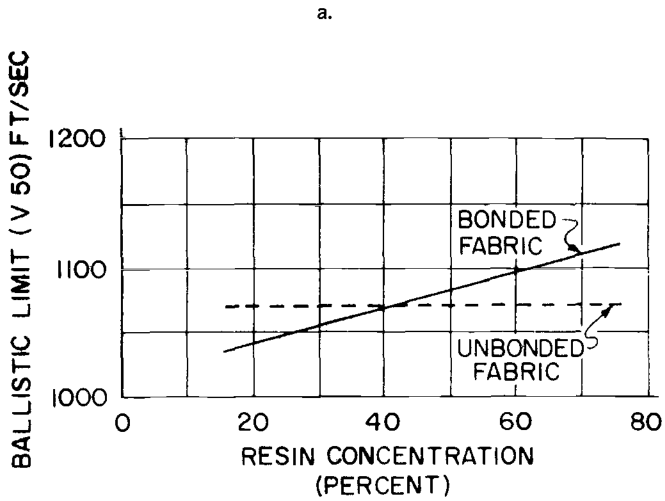
*An air accident is defined as "survivable" if the crash forces involved are within the limits of human tolerance (50 to 150 G's transverse to the spine) and any portion of the inhabitable area of the aircraft is not collapsed sufficiently to impinge upon or crush vital areas of a person seated in a normal position.[1]

*Transient deformation is the deflection of a material under an impact load and the rapid recovery when the load is removed. This deformation is of extremely short duration.

Fig. 1. Helmet flying protective—l, crash and ballistic protective helmet; r, standard army helmet, APH-5.

Abraham L. Lastnik, Technologist at U. S. Army Natick Laboratories, Natick, Massachusetts, attended Temple University, Philadelphia. He later completed the U. S. Army Management Engineering Training Agency course in Value Analysis. His research and development efforts in Army protective material have found applications in combat helmets for ground, vehicular and flight personnel.

Mr. Lastnik holds several patents relative to head and face protection. He is a member of the United States Standards Institute Z90 Committee on Vehicular Head Protection.



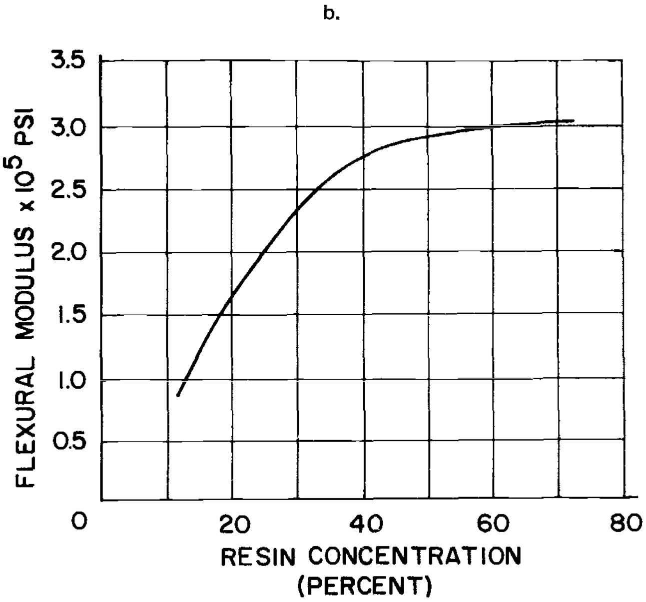


Fig. 2. Resin concentration—a, effect of resin concentration on ballistic limit of nylon fabric laminate (9 plies); b, effect of resin concentration on flexural modulus of nylon fabric laminate (9 plies).

fragments (Figure 2a).

2. The energy absorbed by the laminate increases with its increased resin concentration.

3. Resin content in excess of 40 per cent increases the weight of the laminate without significantly affecting its flexural modulus (Fig. 2b).

Resin content of 35 to 40 per cent was therefore selected for the shell of the improved protective nylon helmet for Army aircraft crewmen. The shell is a laminate of 9 layers of nylon fabric consisting of four pinwheel patterns and five smaller circular patterns. These are assembled, as shown in Figure 3, into a preform consisting of nine plies of fabric extending from the crown to the brow line and around the helmet, and feathering to four plies at the edge of the ear sections. This structure, bonded with between 35 and 40 per cent resin content, will resist penetration and deflection and, as a result of its flexural characteristics, absorb some impact forces and distribute the residual forces over a large surface area.

Irreversibly crushable foamed plastic (4 pounds per cubic foot density expanded polystyrene resin, nominally ½-inch thick), which is used as the energy-absorbing liner, absorbs impact energy and thereby attenuates

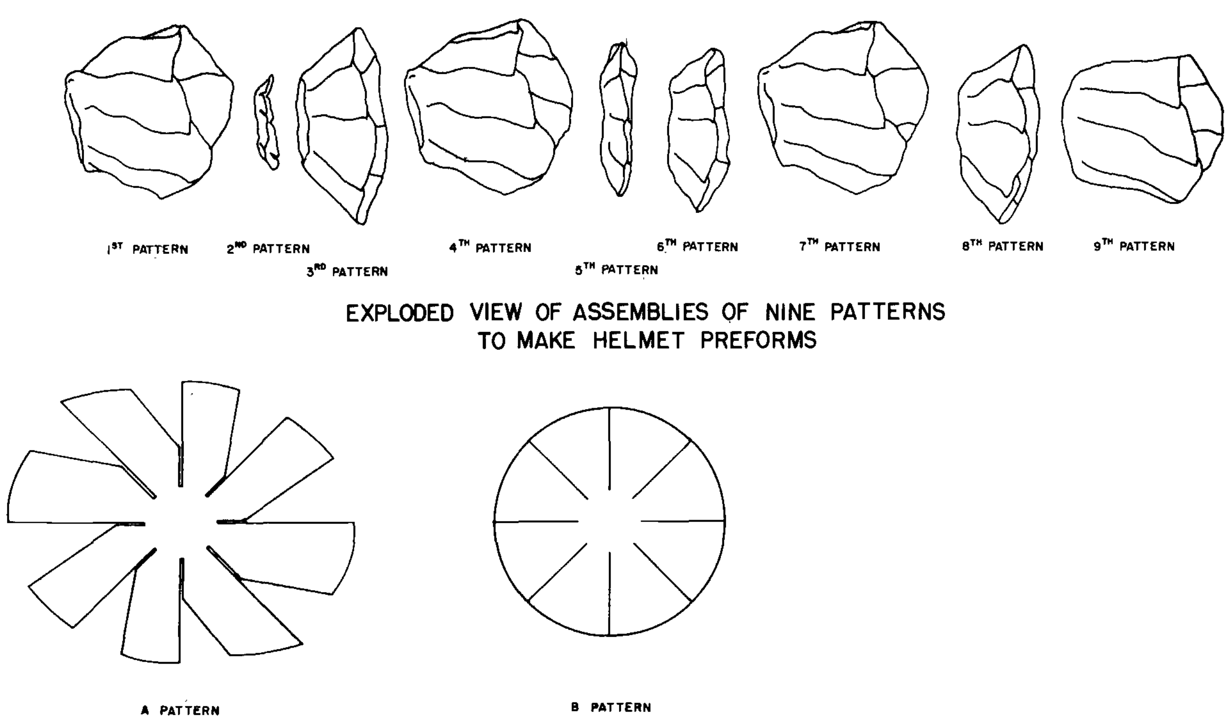


Fig. 3. Preform assembly for flight helmet.

the impact forces before they reach the head.

The interliner, considered an integral component of the sizing system, is made of ¼-inch thick, slow-recovery material (7 pounds per cubic foot density expanded polyvinyl butadiene acrylonitrile plastic blend). Although this material is not suitable for providing protection against high-level impact, it is a satisfactory shield against the bumps and buffeting encountered during combat operations. The slow-recovery characteristics of the interliner will preclude damage of the crushable liner caused by continuous exposure to low-level impact.

A resilient material, such as expanded latex, is at best a comfort feature. Soft resilient pads of various thicknesses are adhered to the interliner to adjust the size and fit of the helmet.

METHODS

Impact tests on the nylon helmet were conducted with a drop type of apparatus (Figure 4). In these tests, a 16.3-pound mass with 1.9-inch radius impacting surface is dropped onto a free-swinging hollow headform assembly made of cast magnesium alloy weighing 13 pounds. An accelerometer, mounted on the inner surface of the headform directly below the point of impact, is connected to an oscilloscope that records acceleration as a function of time.[8] The helmet, with visor housing and visor removed, but with the guide tracks and sizing pads in place, is mounted on the instrumented headform. The impactor is then dropped from predetermined heights to obtain the desired impact forces and velocities. The resulting acceleration time traces on the oscilloscope were photographically recorded.

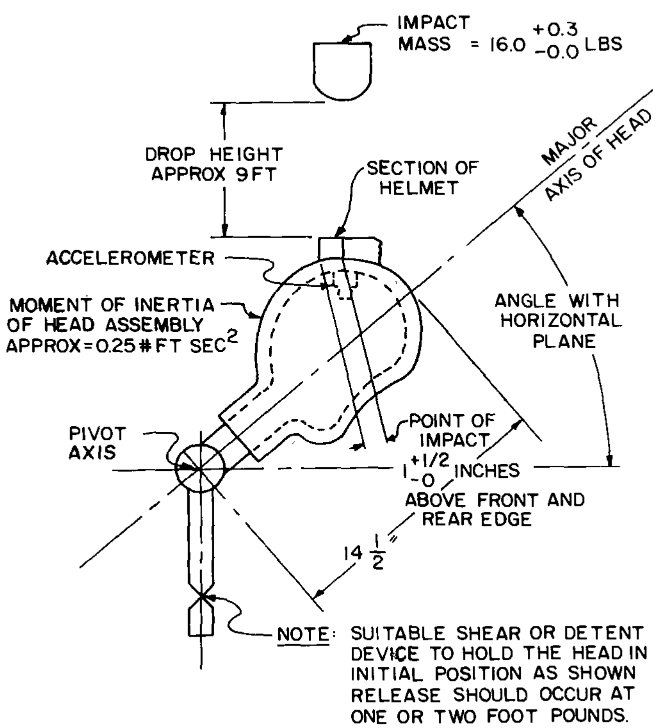


Fig. 4. Schematic: helmet impact test apparatus.

Resistance to fragment penetration was evaluated by the standard ballistic acceptance test for Army personnel armor material[2] to determine the helmet's V50 ballistic limit.* The projectile used for this evaluation is designated as a caliber. 22, T37 (17-grain) fragment simulator that has a hardness of Rockwell C30-2.

RESULTS

Effect of Nylon vs. Glass—The feasibility of the new improved flight helmet was first explored by comparing the impact-energy attenuation characteristics of molded nylon shells (made in the same molds as the standard glass flight helmets) and the glass helmet. Both helmets were then impact-tested in accordance with the military specification for the Navy pilot's helmet APH-6,[5] a method similar to that detailed in the previous section.

When subjected to two successive impacts of 100 foot-pounds in the same area, the nylon helmet showed no evidence of "bottoming"† and no accelerative forces greater than 130 G's were transferred to the instrumented headform. Similar impacts on the glass helmet imparted 300 and 600 G's, respectively. The time duration of the impacts ranged from 6 to 11 milliseconds for the nylon helmet and from 2 to 4 milliseconds for the glass helmet.

Effect of Size—By adjusting the mold dimensions to account for the greater bulk of the nylon laminate structure, large as well as smaller nylon helmets (designated as large and regular size) were made. Both the large and regular size helmets were impact-tested in four areas (front, rear, left and right sides). The results (Table I) show that the difference in size does not significantly affect impact-energy attenuation characteristics.

Effect of Repeated Impacts—The same test procedure was used by the Snell Memorial Foundation to measure the helmet's impact-energy attenuation characteristics.

*V50 ballistic limit is the impact velocity at which the probability of penetration of a material by a test projectile is 50

†Bottoming is a phenomenon occurring during the impact or crushing of energy-absorbing systems when input energy is transmitted to the sensing element with little or no attenuation.

TABLE I. PEAK ACCELERATIVE FORCES IN G's IMPARTED BY ONE 100-FOOT-POUND IMPACT

Impact Site	Regular Size	Large Size
Front	63.2	66.0
Rear	57.2	61.9
Left Side	89.8	85.8
Right Side	81.8	87.0

TABLE II. PEAK ACCELERATIVE FORCES IN G's IMPARTED BY EACH OF TWO SUCCESSIVE 144-FOOT-POUND IMPACTS

Impact Site	First Impact	Second Impact
Front	230	250
Rear	220	250
Left Side	210	230

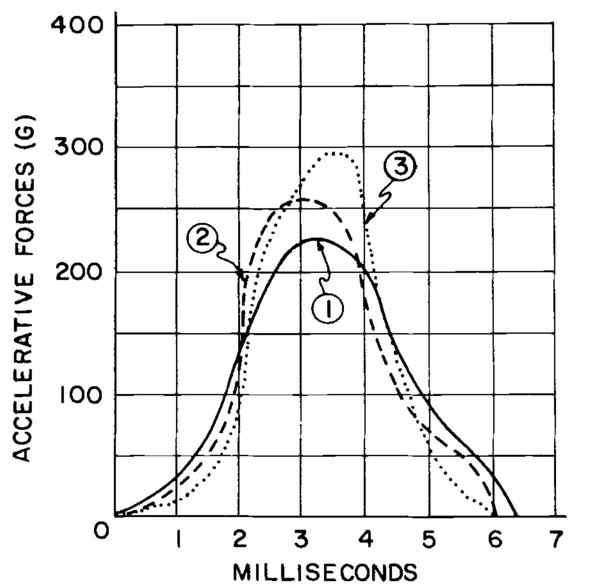


Fig. 5. Helmet impact test—three successive 144-foot-pound impacts on the front center of a nylon helmet.

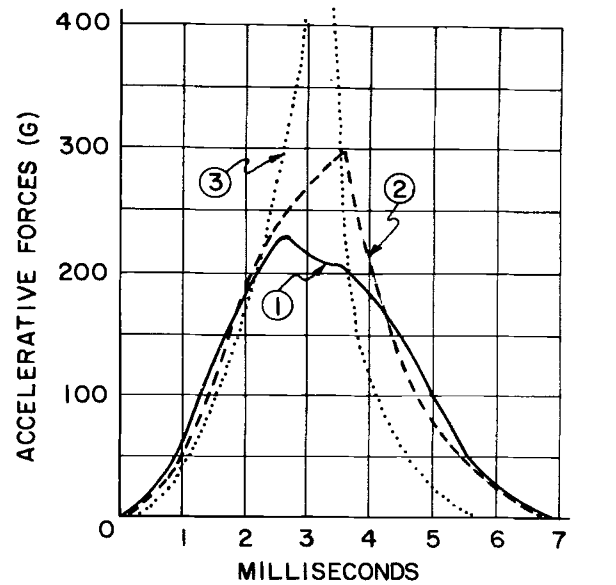


Fig. 6. Helmet impact test—three successive 160-foot-pound impacts on the front center of a nylon helmet.

Two successive impacts were made on the helmet in each of four areas situated on a locus of points from 1 to 1½ inches above the horizontal plane described by the front and rear edges of the helmets.

The differences in impact-energy attenuation among the sites were negligible (about 20 G's difference in each impact series) as shown in Table II. The uniformity of these results reveals the consistency in the design and construction of the nylon helmet.

Figures 5 and 6 show characteristic acceleration time curves for three successive impacts on the front of a nylon helmet (without the visor assembly) at 144 and 160 foot-pounds, respectively. The first impact on each generated forces, in the instrumented headform, of less than 230 G's; the second impact on the same site generated forces of 300 G's or less. The third 144-foot-pound impact generated a force of 300 G's; the third 160-foot-pound impact caused the helmet to bottom and generated forces in excess of 400 G's. The duration of all the G forces, except those that caused bottoming, was at least 6 milliseconds.

Effect of Projection—Projections on the surface of a helmet would normally be expected to be areas of energy concentration upon impact; therefore, particular emphasis was given to the effects of impact on the molded nylon visor guides. One of these projections (about ¼-inch high and ½-inch wide) was impacted with 144 foot-pounds of energy for six successive impacts. None of these impacts generated more than 300 G's in the instrumented headform. This is in sharp contrast to the results when metal guides are used as on older Army and Navy flight helmets. Metalic projections are relatively inelastic and are sources of stress concentration, whereas the nylon visor guides attenuate the energy. This unexpected occurrence is probably caused by the breaking up of nylon material.

Ballistic Test—The average areal density* of the helmet shell is 17.86 ounces per square foot of surface. Because the ballistic limit is a function of areal density, the helmet was evaluated as two structures, each with a different areal density. Density was not determined experimentally, but was calculated to be 19.65 ounces per square foot in the crown and 13.10 ounces per square foot in the ear sections. The V50 ballistic limits of these structures were thus found to be 1163 and 1045 feet per second, respectively.

*Areal density is the weight per unit area, a measure for comparing the relative effectiveness of armor materials.

ACKNOWLEDGMENT

Appreciation is extended to the Snell Memorial Foundation and its Director of Research, George G. Snively, M.D., for their assistance and technical support of the helmet development program.

REFERENCES

1. Army Aviation Helmet Experience: Analys. & Res. Div., Human Factors Sec., Rpt. HF4-61, U.S. Army Board for Aviation Accident Res., Ft. Rucker, Ala.
2. Ballistic Acceptance Test Method for Personnel Armor Materials: MIL-STD-662, June 61.
3. Bezrah, A. A.: Level and Priority of Protective Requirements. Presented at In-Process Review, Army Aircraft Crewman's Helmet, QMR&E Cmd., Natick, Mass., Sept. 1961.
4. Helmet, Flying HGU-2A/P: MIL-H-26671A, March 1961.
5. Helmet, Pilot's Protective Type APH-6: MIL-H-22995.
6. Helmet, Combat Crewman's: MIL-H-43059, Feb. 1962.
7. Lastnik, A. L., and Gates, J. W.: The Effect of Resin Concentrate on Physical Properties of a Laminated Structure for a Crash and Ballistic Protective Helmet. Clothing Br Series Rpt. No. 29, Clothing & Organic Materials Division, QMR&E Cmd., Natick, Mass., April 1962. Presented at Personnel Armor Symposium, U.S. Naval Res. Labs., Washington, D. C., Oct. 1961.
8. Snively, G. G., and Chichester, C. C.: Safety in Racing. Research Grant No. RG-6094, Nat. Inst. of Health, U.S. Public Health Service.